ALTERNATIVE CONTROL POLICIES FOR WATER QUALITY MANAGEMENT: A SIMULATION GAMING APPROACH

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INTRODUCTION

Objectives of the Research

Increasing diversion, withdrawal, and use of water has placed a burden on both the quantity and quality of existing supplies, raising costs of both delivery and treatment, and presenting more difficult problems of allocations and quality management. These facts have motivated government decision makers to seek more cost-effective means for managing water quality.

The use of economic incentives for managing water quality has drawn a great deal of support from economists. However, the response of water quality managers to a particular incentive system cannot be predicted without analysis. Before any incentive system is implemented, its effectiveness has to be determined. Experimental economics provides a mechanism for testing the effectiveness of such a system.

Proper training of water quality managers is also an important dimension in the overall water resource management picture. While engineering and business programs provide enough theoretical training to help these managers make the right decisions, experiential learning can complement this training further.

The objectives of this research were (i) to refine a water quality management simulation model which can be used as a training vehicle for water quality managers, and (ii) to use this model as a research tool for exploring the effectiveness of managing water quality through different control techniques. These results should be helpful in designing an institution for efficient water quality management.

Nature of the Problem and Relevant Research

The use of economic incentives for managing water quality has drawn a great deal of support from economists. The exact specification of economic incentives can take many different forms, but more recent analytical attention has focused on the use of transferable discharge permits (TDP's) for achieving water quality objectives. Tietenberg (1980) has noted several reasons for this. First, a TDP system could be used to replace the current purely regulatory system with the potential benefit of achieving a higher level of water quality at a substantially reduced commitment of resources to pollution abatement. Second, because inventories of excess pollution rights permits can be sold, a TDP system provides polluters with incentives to adopt pollution control technologies which provide greater levels of pollution abatement at a lower resource cost. This process provides an economic incentive for developing and adopting new pollution abatement control techniques.

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A number of methods are available that could be used to evaluate the effectiveness of TDP's. David et al. (1980), Eheart et al. (1980), O'Neill (1983), and O'Neill et al. (1983), for example, use mathematical programming models to evaluate the effectiveness of TDP's. David et al. (1980) discuss the possibility of using TDP's to control phosphorous discharges from the State of Wisconsin while Eheart et al. (1980) report on the results of this proposal. The latter paper is based on a mathematical programming model that was developed to simulate the operation of a single-price auction of TDP's. Permits were either sold at auction or initially distributed free to dischargers on the basis of some agreed-upon formula and subsequently redistributed among dischargers by auction. The sales method and four alternative free initial allocation schemes were examined and found to be similar in many respects. It was anticipated that if the TDP system would yield a cost minimizing combination of treatment efficiencies, the cost savings would be roughly $750,000 per year relative to a uniform treatment policy. O'Neill used a multiperiod model to examine the performance of a TDP market under conditions of varying stream flow and temperature for Biochemical Oxygen Demand (BOD) discharges to the Fox River in Wisconsin. This analysis showed that the direct regulatory approach was about 40% more costly than the minimum-cost potential market solution. "Under the 'worst case' flow-temperature scenario the analysis showed that up to $7 million could be spent annually on the management of a market before the market would be a less-preferred strategy" (O'Neill, 1983, p. 812). The study by O'Neill, et al. (1983) showed that if permit markets were working perfectly, they would lead to reduced costs of roughly $8 million on the Fox River.

All of the studies above were conducted using mathematical programming models. However, optimization models presuppose some form of rational behavior on the part of managers, such as profit maximization or cost minimization. A viable alternative to mathematical programming models for assessing the effectiveness of TDP's is experimental economics. Experimental economics has been utilized in various phases of economic research (see, for example, Hahn (1983), Plott (1982), Plott (1983), Hoggatt et al. (1976), Smith (1982), Smith et al. (1982) and McInish (1981), Freejohn and Noll (1976), Miller et al. (1977). Weber (1974) notes that experimental economics is different from other forms of economic analysis because an attempt is made to establish a controlled situation in which "...subjects are asked to participate by making the remainder constant. Behavior of the subjects with respect to the simulation situation can be observed as some elements are changed" (Weber, 1974, p. 3).

Friedman (1963) notes a number of advantages of experimental economics. First, experimental economics may be helpful for examining economic theories involving simplified situations. Experimental economics allows the researcher to establish a similar situation and test the behavior of subjects under consideration. Other advantages include the difficulty of getting empirical data from industries, the fact that such data are not always in the form needed by economists, and the ability of the experimenter to design a situation containing only those elements of particular interest. One possible disadvantage concerns the motivation of subjects and their time horizon relative to that of the actual decision makers.

Experimental economics, also known as simulation gaming, has been used in business schools for introducing complex decision making. Henshaw and Jackson (1984) describe one such executive decision game. These games have also been used for research. A number of management information systems issues have been researched using such systems. For example, Sharda and McDonnell (1984) describe a test of effectiveness and efficiency of a Decision Support System (DSS) using an executive decision game.

Simulation gaming has been employed as a tool for training and research in water resources management. Wright and Howell (1975) describe a simulation game for water resources development in New South Wales. Palmer et al. (1979) reported that PRISM, a game developed by them, was valuable in identifying issues of water supply management to decision makers at various agencies in the Potomac River Basin. Diamond et al. (1984) discuss the design of a simulation game to teach and research issues in drought management.

Our literature search shows that experimental economics has not been designed for water quality management decisions, particularly from the participating firms' viewpoint. Such an exercise would be valuable in teaching various aspects of water decisions; it could also be used as a research tool in understanding economic issues of water quality management. For example, there is a great deal of interest in replacing the current direct regulatory or command and control approach with some type of economic incentive system, such as a tax or discharge permit market for managing water quality. The perceived benefit of such a change is in achieving a sizable reduction in the cost of meeting water quality objectives. That is, the water quality outcomes based on the use of economic incentives are considered to be cost effective.

Hahn (1983) and Plott (1983) have used experimental economics to examine the effectiveness of TDP's. Our approach differs from theirs in that it represents the discharger's decision making problem in a more complex environment. In particular, the discharger must make a decision on the level of production activity to be undertaken each period, along with decisions on the disposition of waste water flows generated from production activity. Waste treatment facility investment decisions are also included in the water quality management simulation model. The structure of the water quality management simulation model is described in an appendix.

The complexity of the decision making environment in the water quality management simulation model provides an excellent vehicle for addressing questions of discharger compliance with respect to allowed discharge levels. This research will also provide a means for designing and evaluating an institutional framework for an improved monitoring and enforcement system (Russell et al., 1986).

METHODS AND PROCEDURES OF RESEARCH

Research for this project was conducted using a simulation model developed in an earlier project funded by the Oklahoma State University Center for Water Research.

Purposes

The simulation model previously developed has two purposes. The first purpose of the model is to use it as a training vehicle for managers responsible for making decisions pertinent to water quality management. All manufacturing firms which release some type of pollutant as a result of their production operations are responsible for meeting certain water quality standards. Similar standards also have to be met by municipal treatment plants. These standards are usually met by either installing appropriate pollution control or treatment equipment, by transporting the effluent to a municipal or private treatment plant, or by releasing the effluent into a river or pond based on a permit granted by a regulatory agency. The person responsible for water quality management has many alternatives. The simulation model allows decision makers to understand the process of water quality management decisions as well as the effects of their decisions. The simulation initially has defined water quality as it pertains to biodegradable wastes. This can be modified in the future to include toxic wastes.
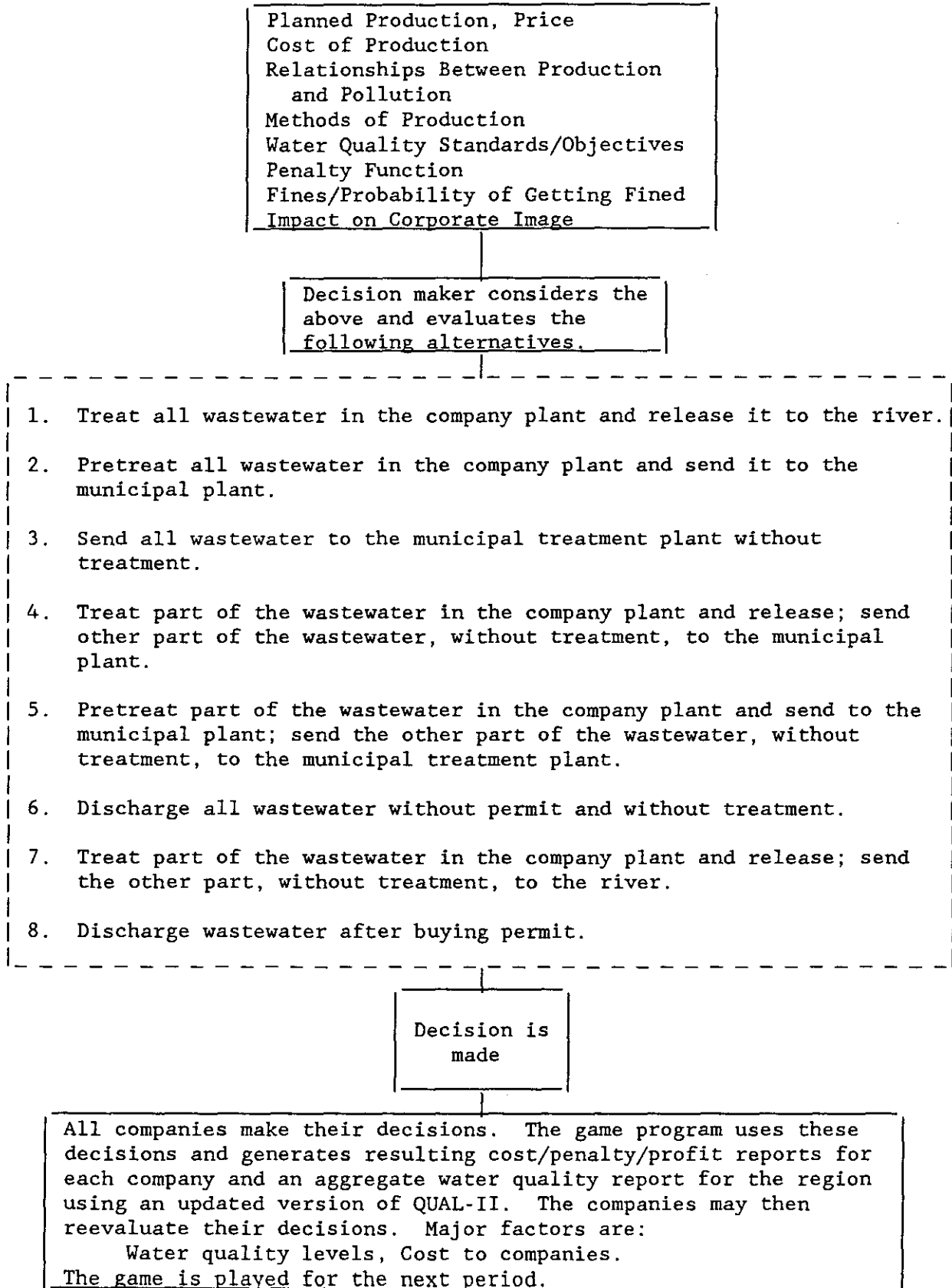
The second purpose of the simulation model is to use it as a research tool in understanding the behavior of water quality managers. Specifically, we used the simulation model to explore the feasibility of implementing a transferable discharge permit system as a tool for managing water quality. We administered the simulation model first without offering TDP as an alternative. After a few weeks, the simulation included TDP as an option for water quality decisions. We identified the differences in the managers' behavior and the overall water quality levels.

Basic Model Structure

The flowchart in Figure 1 illustrates the basic structure of the simulation model. The participants are given a detailed description of the firm or the municipality they are supposed to represent. This narrative for firms includes data on planned production, cost of production, relationships between output and emission of various pollutants. For municipal managers, the information contains data on expected city waste load and demand from firms in the area for treatment. The participants are also informed about the water quality standards that the firm or the city must meet. Some firm participants receive information on whether their firms could get away with releasing effluent without treatment. This includes the estimated penalties and probability of getting fined. The narrative also includes a description of their corporate culture and their concern for corporate citizenship.

In addition to the production data, the manager is also given a complete description of alternatives. These alternatives are described later in detail. Relevant cost/capacity effectiveness figures are provided for each alternative. Costs are provided for various levels of treatment using different plant capacities.

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Figure 1: WATER QUALITY MANAGEMENT GAME

```
| Planned Production, Price                    |
| Cost of Production                           |
| Relationships Between Production             |
|   and Pollution                              |
| Methods of Production                        |
| Water Quality Standards/Objectives           |
| Penalty Function                             |
| Fines/Probability of Getting Fined           |
| Impact on Corporate Image                    |
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| Decision maker considers the  |
| above and evaluates the       |
| following alternatives.       |
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1. Treat all wastewater in the company plant and release it to the river.

2. Pretreat all wastewater in the company plant and send it to the
    municipal plant.

3. Send all wastewater to the municipal treatment plant without
    treatment.

4. Treat part of the wastewater in the company plant and release; send
    other part of the wastewater, without treatment, to the municipal
    plant.

5. Pretreat part of the wastewater in the company plant and send to the
    municipal plant; send the other part of the wastewater, without
    treatment, to the municipal treatment plant.

6. Discharge all wastewater without permit and without treatment.

7. Treat part of the wastewater in the company plant and release; send
    the other part, without treatment, to the river.

8. Discharge wastewater after buying permit.

```
| Decision is  |
|    made      |
```

```
| All companies make their decisions.  The game program uses these     |
| decisions and generates resulting cost/penalty/profit reports for    |
| each company and an aggregate water quality report for the region    |
| using an updated version of QUAL-II.  The companies may then         |
| reevaluate their decisions.  Major factors are:                      |
|       Water quality levels, Cost to companies.                       |
| The game is played for the next period.                              |
```

The manager/participant considers all of the relevant information, evaluates the alternatives and makes a decision. The decision is in terms of an alternative and appropriate size-cost data. The decision can also include investment in a new treatment plant. If selected, the new plant would be available in one year.

When the participants representing a firm have made a decision, they enter the data into the computer simulation model. The simulation model then prepares two reports. Based on the decisions of all the firms, the production-pollution relationships calculate the generated discharges. The abatement options selected by managers are used to calculate their costs and the quality of effluents. The model also prepares a water quality report for the entire region using the QUAL-II model and other parameters. The model allows multipoint sources of pollution and calculates water quality in terms of BOD, phosphorus and nitrogen.

Each participant gets a computer generated report summarizing the effects of his/her decisions. This report includes the actual costs incurred, fines levied for not meeting standards, achievement of pollution clean-up objectives, and so on. The participant also receives information that a firm/city would be able to get in general, such as overall quality of water in the stream at different locations.

The simulation model is then implemented again for the next period, i.e., next quarter. Details of these steps follow.

Participant Characteristics

In its current version, the model simulates a region consisting of five industrial firms and two municipalities. Each player represents either a firm or a municipality. Teams of two or more for each industry or municipality can be used to include more participants. A schematic of the region is given in Figure 2. As seen in Figure 2, the industries and cities are located along a river and its tributaries. The numbered elements in the figure represent 'mile-markers.' For example, team 2 is located 4 miles from team 1.

It is assumed that the first three industrial firms are located in Paladine City and the other two are in Eddyville. The five industries selected in this simulation model represent industries which generate significant biochemical waste. This version of the game only considers biochemical waste; it does not consider toxic waste substances. Future revisions of the model could include treatment of toxic wastes as well.

The industrial firms represent a cotton processing plant, a poultry processing plant, a meat processing plant, a potato chip factory, and a pulp-and-paper mill, respectively. These plants range from small to medium in size within their industries. A narrative is given to each participant describing the production function of the firm. It includes the production forecast for four quarters, the associated expected waste water flow rates in million gallons per day (MGD), and the influent Biochemical Oxygen Demand (BOD) in milligrams per liter (mg/l). The narrative specifies the
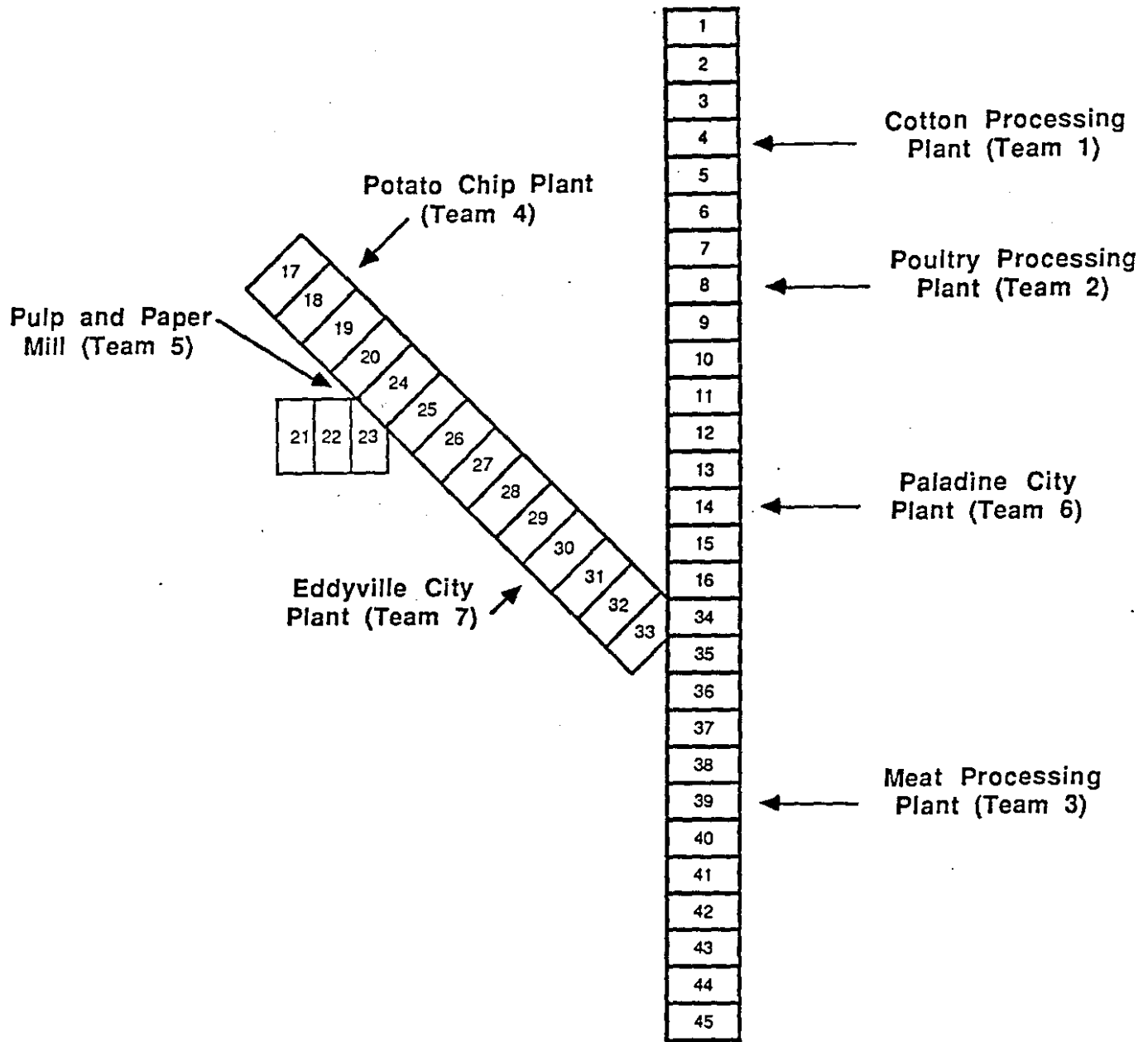
Figure 2 : A Typical River Region Consisting of
Industries and Cities

Table 1: Some Initial Parameters for Participants

Team No.	Description	Max. Permitted Discharge		Plant Capacity		Production Data*	
		Flow (MGD)	BOD (mg/l)	Flow (MGD)	BOD (mg/l)	Flow (MGD)	BOD (mg/l)
1	Cotton Processing Plant	1.70	30	1.50	20	1.20	200
2	Poultry Processing Plant	0.38	24	0.45	24	0.50	300
3	Meat Processing Plant	0.03	40	0.05	70	0.04	400
4	Potato Chip Factory	0.04	20	0.05	20	0.04	100
5	Pulp and Paper Mill	2.00	20	2.00	40	2.00	400
6	Paladine City	26.70	45	20.00	40		
7	Eddyville City	5.60	10	8.00	10		

*These are based on production forecasts for first quarter. These can be changed by the students.

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permitted discharge to the river in terms of maximum flow (MGD) with limits on BOD concentration in the effluent. A description of the capacity of the available waste water treatment plant is also provided. This is followed by a statement about the estimated fixed cost as well as variable costs of operating the waste treatment plant at various levels. Estimated user charges at different flow rates and pretreatment levels are also included, in case a firm should decide to use the municipal plant for disposal of waste water. A table containing costs of larger plant sizes is provided to aid in making decisions on upgrading the plant.

Plant sizes, permits and production forecasts exhibit a wide range among the five industrial firms and the two municipal teams. Table 1 includes a summary of starting values of permits, plant sizes and production forecasts. The wide range appears to be quite realistic based on our interviews with representatives of many of the regulatory agencies in the State of Oklahoma. In any case, these numbers can easily be updated.

Decisions and Alternatives

In each period, participants have to make two types of decisions. They first decide on how to dispose of the waste expected to be generated in the current period. Then they decide on whether to upgrade the company plant. In the former decision, six alternatives are normally available. These are:

1. Treat all waste water in the company plant and release it to the river.

2. Pretreat all waste water in the company plant and send it to the municipal plant.

3. Send all waste water to the municipal treatment plant without treatment.

4. Treat part of the waste water in the company plant and release; send other part of the waste water, without treatment, to the municipal treatment plant.

5. Pretreat part of the waste water in the company plant and send it to the municipal plant; send the other part of the waste water, without treatment, to the municipal treatment plant.

6. Discharge all waste water without permit and without treatment.

7. Treat part of the waste water in the company plant and release; send the other part, without treatment, to the river.

8. Discharge waste water after buying permit.

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The first alternative involves treating the waste fully in the company plant. It results in the company incurring capital as well as operating costs of a treatment plant. The next four alternatives make use of the municipal plant to some extent and thus involve the expense of a user charge. The last sixth alternative is really an unacceptable one. If a company selects this alternative and is caught, a heavy fine is imposed which is to simulate a penalty as well as bad publicity.

The decision to select an alternative from these is not an easy one. One needs to calculate total cost of each alternative. In some alternatives involving partial treatment, one also needs to consider the extent of treatment and its effect on total cost. Some of the alternatives may not be feasible, given the capacity of the treatment plant and/or the permitted flow. For example, if a firm has a waste treatment plant with a design capacity of 0.08 MGD and expects a 0.07 MGD flow this quarter, but its permit allows a discharge of only 0.06 MGD, the company cannot select the alternative of treating everything in the company plant and releasing to the river. The decision maker has to select the feasible set of alternatives first, then analyze their implications and make a decision. Another factor to consider is the continuity from quarter to quarter. Realistically, one does not change such decisions month to month. Thus, the long term effect of a strategy also has to be considered.

A similar reasoning also applies to the decision to upgrade the plant. This decision may affect future decisions as well. One has to weigh the benefits of a larger plant against its costs as well as costs of alternatives such as "pretreat the waste and release to the city sewer" or "treat only part of the waste and release to the river and send the other part to the city plant." Both of these decisions involve a good deal of analysis or marginal costs of each alternative.

Inputs by Simulation Model Administrator

Once the participants have made their decisions and entered them into a computer dataset, the administrator can specify the expected ambient temperature, other flow conditions in the region, and so on. In the simplest form, all such environmental conditions can automatically be generated through a computer program if the administrator specifies a season for the quarter under consideration. Thus four sets of environmental conditions are built in, one for each season.

Simulation Model Program Calculations

When participants and the administrator have entered their information, the main program is called to simulate economic as well as water quality effects of the decisions. A financial report is generated for each team, summarizing their decisions, their plant report, and cost analysis of their decision. Reports for industrial firms also include a simplified income statement based on their production decisions and fixed relationships between production, price and cost of goods sold variables. A sample financial report is exhibited in Figure 3.

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     WATER QUALITY SIMULATION GAME

    REGION                           : A
    GAME PERIOD                      : 1
    REPORT FOR TEAM                  : 3


        DECISIONS FOR WATER QUALITY MANAGEMENT
    CURRENT DESIGN CAPACITY                      :  0.050 MGD
    CURRENT DESIGN BOD EFFLUENT CONCENTRATION: 70.0    MG/L
    CURRENT MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO THE RIVER:  40.0 MG/L
    THIS IS INDUSTRIAL FIRM
    PRODUCTION FORCAST                           :  1.000 MILLION POUNDS OF PRODUCT
      EXPECTED WASTEWATER FLOW RATE              :  0.038 MGD
      EXPECTED BOD INFLUENT CONCENTRATION        :400.0    MG/L


        THIS IS YOUR ALTERNATIVE
    PRETREAT EVERYTHING IN THE COMPANY PLANT & SEND TO THE MUNICIPAL PLANT.
    PRETREATED WASTEWATER FLOW RATE              :  0.038 MGD
    EXPECTED BOD EFFLUENT CONCENTRATION          :280.0    MG/L


    DESIGN BOD REMOVAL RATE                      :   0.82


        THIS IS YOUR UPGRADE PLAN
    FUTURE DESIGN CAPACITY                       :  0.050 MGD
    FUTURE DESIGN BOD EFFLUENT CONCENTRATION : 60.0    MG/L


        WATER QUALITY-RELATED COSTS
    QUARTERLY   INVESTMENT AND FIXED OPERATING COSTS OF PLANTL:   7081. DOLLARS
    OPERATION COSTS                         :    3707. DOLLARS
    INDUSTRIAL USER CHARGES                 :    1391. DOLLARS
    PRICE OF PERMIT                         :       0. DOLLARS
    TOTAL CURRENT COSTS                     :   12179. DOLLARS


        PROFIT & LOSS STATEMENT
    TOTAL SALES REVENUE                     : 1800000. DOLLARS
    LABOR AND MATERIAL COSTS                : 1080000. DOLLARS
    OTHER EXPENSES                          :  180000. DOLLARS
    TOTAL EXPENSES                          : 1272179. DOLLARS
    TOTAL TAXABLE INCOME                    :  527821. DOLLARS
    TAX ON CURRENT INCOME                   :  242798. DOLLARS
    NET EARNING                             :  285023. DOLLARS
```

Figure 3

Considerable effort was made to ensure the accuracy of the relationships included in the game program. For example, fixed and variable cost formulae for operation of a waste treatment plant are based on statistical analyses reported by Fraas and Munley (1984). The relationships were developed over a sample of 62 and 178 plants, respectively. User fees for use of a municipal plant are calculated using formulae proposed by Dyer et al. (1981), again based on a statistical analysis. This formula was modified because it establishes user charges on the basis of BOD, nitrogen and phosphorus contents of the waste water and we assume BOD is the only metric for measurement of water quality.

If a decision maker decides to release untreated water without appropriate permits, the simulation model program attempts to simulate reality by randomly deciding whether the team is caught by inspectors. A random number between 0 and 1 is generated. Assuming that there is a 60% probability of getting caught, this random number is translated to a fine or no fine.

A second component of the simulation model is responsible for simulating the water quality of the whole region, based on various point discharges and environmental conditions. We use a program called QUAL-II for this purpose. This program, or versions of it, has been used by the Environmental Protection Agency (EPA) and local regulatory agencies in simulating steady state water quality as well as in establishing point loads for various dischargers. This program is an extension of Streeter-Phelps equations and is able to consider multiple input sources and ambient conditions in determining the spatial distribution of water quality as measured by BOD, dissolved oxygen (DO), nitrogen and phosphorus. The use of QUAL-II in simulating the water quality effects of individual decisions enhances the reality of the simulation model.

METHODOLOGY

The simulation model in its new form could be used as a research tool for answering many of the research questions posed earlier. Within the duration of this project, we expected to answer at least one of the questions, i.e., is a transferable discharge permit system an effective way of managing water quality?

We first present a background for the hypotheses of our experiment. Then we describe the experimental method. This includes an explanation of subjects used in the experiment, overall procedures, and bidding method for permits. Operationalization of measures is described next, followed by our results.

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Development of Hypotheses

The hypotheses tested in this research are based on commonly accepted properties of pollution rights markets. Some of the more important properties will be summarized briefly. It is generally argued that the pollution control policy which is based on a market oriented mechanism will be more cost-efficient than alternative policies such as direct regulation. Moreover, it is argued that permit exchanges among dischargers provides potential for improvement in environmental quality while lowering overall costs. Incentives for the development and adoption of innovative waste-reduction practices are also provided.

There are at least two other advantages of the TDP system (Eheart, Brill and Lyon, 1983). First, this system allows achievement of cost-efficiency without placing an additional financial burden on dischargers. Second, TDP programs allow the government to control the aggregate level of waste discharge directly. Based on the previous background, two hypotheses were proposed. The first hypothesis was concerned with the cost-effectiveness of a TDP system.

> Hypothesis 1: All other conditions being the same, the total cost of treatment for a group of dischargers will be lower with a marketable permit system than with a direct regulatory system.

Even if a TDP system results in cost savings, it may not be acceptable to society if a resultant water quality worsens. The economic rationale presented earlier states that the savings can be achieved without any loss of water quality. The second hypothesis was designed to test this statement.

> Hypothesis 2: The overall water quality of a region will not be reduced when a direct regulatory system is replaced with a transferable discharge system.

Method

Subjects:

Participants in this study were students in a Natural Resource Economics class. Subjects were randomly assigned to one of the particular firms within the region. They were given a case description of the firm/city they were supposed to represent. A sample case study is included in the appendix. The subjects were also given an example of the decision process to determine what alternative is appropriate for a firm, with or without the TDP system.

Measures and Operationalizations

Independent Variable:

The purpose of this experiment was to test if a TDP system results in a lower cost without significant loss of water quality. It was not designed to determine the optimal parameters of such a TDP system. Thus, only a particular TDP system was employed. Presence or absence of this TDP system was the only independent variable in this experiment.

The TDP system employed by us is typical of the ones others have reported. In our case, a marketable permit is equivalent to 1 pound of BOD load per day. The initial allocation of permits to firms is made free, based upon their limits as stated in their waste load allocations. For example, if the state permits firm 1 to release 1.7 million gallons per day with no more than 30 mg/l of BOD, this would be equivalent to 424.83 pounds of BOD per day. So firm 1 is given an initial allocation of 424.83 permits.

Two major approaches have been suggested for the initial allocation of permits (Eheart, Brill and Lyon, 1983). The first one is based on the government selling the permits initially to all dischargers. In this case, the government must decide on the type of procedure (e.g., auction) as well as the disposition of the revenue generated from selling the permits.

The second approach is based on a free initial distribution of permits. In this case, the government must decide the basis for making an initial distribution of permits. Eheart et al. (1980) have suggested four possible schemes for making the initial distribution of permits. One scheme which is of particular interest to this study presumes that a direct regulation program is already in place. an initial allocation of permits is then made on the basis of the direct regulation program as reflected by the status quo of current dischargers. Trading of permits is then allowed to take place. This scheme was used to make the initial allocation of permits.

The auction/bidding procedure for the TDP market was based on a combination of a zero revenue auction and an incentive-compatible auction (Vickery 1961). At the beginning of each period, every discharger was given a free initial allocation of permits based on the waste load allocation distributions received under the direct regulation policy. Each discharger was required to submit binding buying and selling bid schedules to the government. Permits were allocated to the highest bidder with the discharger winning k permits paying the k highest rejected bids of all dischargers except himself. Each bidder thus paid a different price for the permits purchased.

Dependent Variables:

The study was designed to test the effectiveness of a TDP system. Two major determinants of this effectiveness are cost and water quality.

Cost. The cost is defined as the sum of the waste treatment costs of all teams in a region. We are more interested in the treatment costs incurred by the region as a whole than in the cost of a particular discharger. For an individual firm, the treatment costs consist of the fixed and variable costs of operating a waste treatment plant, any user fees paid to a municipal plant plus (minus) the cost (revenue) of (from) permits bought (sold).

Water Quality. Water quality in our experiment was measured in terms of Dissolved Oxygen (DO) and BOD. DO is one of the standard measures of water quality. In reality, DO is instrumentally recorded. However, QUAL-II can simulate levels of DO. Similarly, BOD levels at various points are also estimated by QUAL-II.

While QUAL-II calculates DO and BOD at all of the 45 elements of the simulated region, our dependent variables for the experiment are the following. In any region, the critical point is the one where DO is at its lowest level. DO at the sag point, i.e., at element 45 of the reach, is taken as the most important measure of water quality. Values of both of these measures are recorded from the steady-state simulation reports produced by QUAL-II.

RESULTS AND DISCUSSION

The simulation was run without a TDP system for the first four periods. Then the TDP system was announced, described, and the same simulation was repeated. That is, period 5 is similar to period 1, the only difference being availability of permit trading.

Cost efficiency of the TDP system can be tested by comparing the total water quality related costs with and without the TDP system. Table 2 lists the average water quality costs for each team for the TDP and non-TDP systems. It also includes the signficance level for testing the equality of the means of the two groups. The signficance level is based on Kruskal-Wallis test, since the sample is rather small.

These results indicate that three of the firms realized significant savings in their water quality costs due to TDP system. However, both municipalities incurred higher costs, one of them signficantly. The systemwide costs were higher by about 2%, but the increase was not statistically significant. Thus the evidence of effectiveness of TDP system is only lukewarm, based on our data. A close examination of the data indicates that costs for team 7 increased because team 5 was able to purchase permits and reduce its cost of treatment. In the non-TDP system, team 5 had to pay a substantial municipal user charge to team 7, thereby helping reduce team 7's total cost. With the TDP, team 5 was able to reduce its cost, but team 7 had an increase in the total cost.

Water Quality

Water quality is defined as the value of DO and BOD at sag point, i.e., the element 45 in our region. Table 3 gives the average DO and BOD at element 45 and then the average for the whole system. These numbers indicate that the DO and BOD at the sag point remain unchanged even after the TDP system is introduced. The average BOD level throughout the region increases by a small amount, but it does not seem to affect the DO level enough to cause a deterioration in water quality.

Our results reject the first hypothesis and support the second. That is, no savings in cost were realized for the overall system, but the quality was not any worse with the TDP system than without such a system. These results question the strong positive results obtained by O'Neill et al. (1983). Their results were based on mathematical programming models with several strong assumptions. While our results are also clearly bound by the parameters of the game simulation, it is believed that these are

Table 2: Average Water Quality Costs with and
without TDP System

Team	N	Cost without TDP	Cost with TDP	Differ- ence*	% Savings*	Significance
1	8	96,247	95,069	1,178	1.2%	0.385
2	8	55,272	45,417	9,855	17.8%	0.0433
3	8	11,767	11,581	186	1.5%	0.5637
4	8	9,049	8,604	445	4.9%	0.0433
5	8	214,062	165,626	48,436	22.6%	0.0209
6	8	665,160	685,848	-20,688	-3.1%	0.2482
7	8	243,713	311,059	-67,346	27.6%	0.0209
Region	56	185,039	189,029	-3,990	-2.1%	0.7062

*A negative number indicates increased cost.

Table 3: Average DO and BOD

Measure (mg/l)	N	Non-TDP	TDP	Significance level
DO at sag point	8	5.67	5.67	1.00
BOD at sag point	8	18.93	18.86	0.7728
$DO_{overall}$	180	7.27	7.20	0.6555
$BOD_{overall}$		22.06	23.02	0.0292

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based on more realistic scenarios. These results point to a need for more research, with further refinement of the game program, inclusion of other measures of water quality, and further experimentation. Only then would we be able to establish the effectiveness and efficiency of a TDP system.

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APPENDIX

A Sample Case Study

Synopsis

You are the water quality manager for the Sunbelt Cotton Company. This company is a major producer of cotton fiber products and is located along the Paladine River. The area has experienced a lot of growth in the last 50 years, with a resultant decrease in stream water quality. The State Water Resources Board, as mandated by the Environmental Protection Agency, has established standards or waste load allocations for each discharger along the river. You have a number of alternatives for complying with the waste load allocations. These alternatives are: (I) Treat all wastewater in the company plant and release to the river; (II) Pretreat all wastewater in the company plant and send to the municipal treatment plant; (III) Send all wastewater to the municipal treatment plant without treatment; (IV) Treat part of the wastewater in the company plant and release, send the other part of the wastewater, without treatment, to the municipal plant; (V) Pretreat part of the wastewater in the company plant and send to the municipal plant, send the other part of the wastewater, without treatment, to the municipal treatment plant; (VI) Discharge all wastewater without permit and without treatment; (VII) Treat part of the waste in the company and release it to the river, send the other part, without treatment, to the river; (VIII) Discharge wastewater after buying permit. If the cost of treatment outweighs the marginal profits, you might recommend reducing the production levels. You might also decide to upgrade the plant. Your task is to determine the best alternative for disposing of the current period's waste and decide if any upgrades of the plant should be made.

Description of the Company

The Sunbelt Cotton Company is a large producer of cotton fiber products. Sunbelt's products are sold in a national market with the company having a 9% share of the market. However, the market is very competitive. The company cannot increase prices without a reduction in demand. Also, price promotions are usually copied by competitors as well.

The company was founded by the Simpson family. This family was among the first families to settle in Paladine City and thus chose to locate the plant close to the local river, the Paladine River, so that most of the effluent of the plant could simply be released into the river. This was an effective and inexpensive way to dispose of the waste of the plant. The flow of the river was sufficient to carry all the waste that was generated. The city had a treatment plant which was able to treat the biological waste efficiently. The river water quality was acceptable for body contact recreation and for aquatic life.

As the years went by, other companies located in the area. The city also experienced a lot of growth. Since the founding family, the Simpsons, was very conscientious about the river water quality, they installed a treatment plant in the company to treat the waste. The plant was installed

in 1976, the same year the Simpsons sold the company to a national concern. The plant has not been upgraded since then even though the company has continued to experience a rapid growth. The parent company viewed the treatment plant as an unnecessary overhead.

As the quality of discharge from Sunbelt deteriorated and the city and other companies grew in size, there was a noticeable decline in the water quality of the Paladine River. One other factor in this decline was a new major reservoir upstream which resulted in frequent low flow conditions.

A number of letters to the editor in the local papers was followed by protests to the Water Resources Board from the citizens of Jonesville, a city located 15 miles downstream. The first task of the board was to establish the effect of existing effluent loads on the water quality. An acceptable total waste load was then deduced from the desired water quality target. This total waste load was then allocated among the different dischargers along the river. This was accomplished by allocating to each discharger a claim on the receiving stream's capacity to assimilate waste, which is called a "waste load allocation." These waste load allocations are developed in terms of Biochemical Oxygen Demand (BOD) and its corresponding water quality parameter, Dissolved Oxygen (DO). The waste load allocation is used as the basis for permit limits for each discharger. (Water quality is measured only in terms of BOD levels. While this is a narrow view of the quality of water, this simplification permits us to concentrate on other economic issues.)

You have been hired by Sunbelt to manage its effluent treatment program and are thus responsible for making decisions for treating the company's wastewater. You report directly to the vice president of operations. While you are not directly involved in the production decisions, the V.P. has assured you that your inputs will be given high consideration in making final decisions on production levels.

Production Function

The conversion of cotton fiber into a finished product involves a number of different operations. The cotton is received in bales which are opened and cleaned by machines which blend the cotton while removing a great deal of loose dirt. The cotton is then rolled into sheets ready for the carding and spinning operations. The carding operation combs the cotton, aligning the fibers in parallel prior to spinning them into yarn. Before the yarn can be woven into fabric, it must be strengthened. This is done in an operation known as slashing. The purpose of slashing is to stiffen the fiber by loading it with starch and with other substances called sizing. The sized yarn is then woven into the fabric, brushed, singed and inspected. Finally, the fabric is put through dyeing and finishing operations.

The marketing, finance, and operations departments have developed the final forecasts of production over the next year. The total fabric processed (in millions of pounds) is expected to be as shown in Table A-1.

Even though production fluctuates from quarter to quarter, the company tries to maintain the same payroll. The company has been reasonably profitable to date. A simplified earnings statement indicates that the company can sell its output at $1,200,000 per million pounds of fabric produced. Cost of goods sold is about 60% of sales revenue, exclusive of waste treatment costs. Other expenses are about 10% of sales revenue. The company has a healthy balance sheet. It has very little debt and a $15 million line of credit which is mostly used to finance the purchase of cotton. Last year, the company earned about $1.8 million on sales of about $12 million.

TABLE A-1

PRODUCTION AND EFFLUENT FORECAST

	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
Millions Of Pounds Of Fabric	2.475	2.600	2.800	3.000
Discharge (MGD)	1.200	1.260	1.360	1.460
BOD (mg.1)	200	200	200	200

Effluent

The cotton processing plant in the company has state-of-the-art equipment. However, a large amount of biological waste is generated. The waste is a function of the production volume. The wastewater flow rate is 32,000 gallons of water per 1,000 pounds of output produced and the BOD concentration is 200 mg/1. Based on historical analysis, you have determined that the wastewater discharges and BOD levels in Table A-1 would result if planned production was realized. (Other BOD discharge for any other production levels can be determined by using the participant input program.)

Effluent Removal Strategies

At the present time, Sunbelt's water quality standard has been set at a BOD concentration of 30 mg/1 and wastewater flow of 1.7 MGD. The company's wastewater treatment plant has a wastewater design flow rate of 1.5 MGD and a BOD concentration design level of 20 mg/1.

The options available for complying with the waste load allocations established by Water Resources are:

Alternative 1: Alternative 1 involves "Treat all wastewater in the company plant and release to the river." This alternative is subjected to a number of restrictions; (a) Treated wastewater flow rate should not exceed the plant's design capacity, (b) The treated wastewater flow rate should not exceed the maximum limitation of wastewater flow rate established by the Water Resources Board, (c) The treated wastewater BOD effluent concentration should not exceed the plant's design BOD effluent concentration, (d) The treated wastewater BOD effluent concentration should not exceed the allowed BOD effluent concentration to the river set by the Water Resources Board, (e) the plant's design BOD effluent concentration should not be larger than the allowed BOD effluent concentration to the river. For the TDP case, this restriction will be released.

Alternative 2: The second alternative states "Pretreat all wastewater in the company plant and send to the municipal treatment plant." This alternative will be subjected to the following restrictions: (a) Pretreated wastewater flow rate should not exceed the design capacity, (b) Pretreated wastewater BOD effluent concentration should not exceed the design BOD effluent concentration, and (c) Pretreated wastewater BOD effluent concentration should not exceed the allowed BOD effluent concentration to the municipal treatment plant.

Alternative 3: The third alternative states "Send all wastewater to the municipal treatment plant without treatment." This alternative will be restricted by BOD effluent concentration of discharged wastewater, which should not exceed the allowed BOD effluent concentration to the municipal treatment plant.

Alternative 4: The fourth alternative states "Treat part of the wastewater in the company plant and release; send the other part of the wastewater, without treatment, to the municipal plant." This alternative will be restricted by seven factors: (a) Treated wastewater flow rate should not exceed the production wastewater flow rate, (b) Treated wastewater flow rate should not exceed the plant's design capacity, (c) Treated wastewater should not exceed the maximum limitation of wastewater flow rate to the river, (d) Treated wastewater BOD effluent concentration should not exceed the design BOD effluent concentration, (e) Treated wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the river, (f) Discharged wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the municipal treatment plant, and (g) The design BOD effluent concentration should not be larger than the allowed BOD effluent concentration to the river (for TDP case, this restriction is cancelled).

Alternative 5: The fifth alternative states "Pretreat part of the wastewater in the company plant and send it to the municipal plant; send the other part of the wastewater, without treatment, to the municipal treatment plant." This alternative will be restricted by four factors: (a) Pretreated wastewater flow rate should not exceed the production wastewater flow rate, (b) Pretreated wastewater quantity should not exceed

the design capacity, (c) Pretreated wastewater BOD effluent concentration should not exceed the design capacity for BOD effluent concentration, and (d) Pretreated and discharged wastewater BOD effluent concentraion should not exceed allowed BOD effluent concentration to the municipal treatment plant.

Alternative 6:   The sixth alternative says "Discharge all wastewater without permit and without treatment." This alternative does not have any restrictions.

Alternative 7:   The seventh alternative states "Treat part of the wastewater in the company plant and release; send the other part, without treatment, to the river." This alternative will be restricted by three factors: (a) Treated wastewater flow rate should not exceed the production wastewater flow rate, (b) Treated wastewater flow rate should not exceed the plant's design capacity, (c) The discharge permitted is equal to the initial permit holdings plus traded permits.

Alternative 8:   The eighth alternative says "Discharge wastewater after buying permit." This alternative will be restricted by the fact that the discharge permit needed is equal to the initial permit holding plus buying permit numbers (for TDP case only).

Upgrade Plan: Should your production forecasts indicate that you will not have enough capacity in your company's treatment plant and you decide to treat the waste in your plant, you might decide to upgrade your plant capacity.   The upgrade plant is restricted by the following: (a) The future design capacity is not less than the current design capacity, and (b) the future design BOD effluent concentration is not more than the current design BOD effluent concentration (i.e., quality of treated waste should not be worse than the current quality of the effluent).

If the costs of treatment outweigh the marginal profits, you might recommend reducing the production levels.   It is assumed in the statement of these alternatives that it is not feasible for Sunbelt to install new cotton processing technology.

The selection of any one of the options listed above will involve several types of costs.   These include capital or fixed costs, variable costs, and municipal user charges.   (Fixed costs will always be greater than zero regardless of your decision for handling the company's waste.) These costs vary with the wastewater design flow rate and the BOD design effluent concentration.   As stated above, the wastewater design flow rate for Sunbelt's treatment plant is 1.5 MGD and the design BOD effluent concentration is 20 mg/l.   For this plant, the annual fixed costs are $61,968.00.

The variable costs are shown in Table A-2.   For a given BOD capacity design removal rate, variable costs vary with the actual BOD treatment level and the actual waste flow rate.

The transfer of any amount of waste to the municipal treatment plant involves the payment of a user charge to the municipal treatment plant. The size of this charge will vary with the volume of wastewater flow and the concentration of BOD if it is greater than 250 mg/l. A schedule of user charges for Sunbelt is shown in Table A-3.

TABLE A-2

VARIABLE COSTS ($)

Wastewater (MGD)	BOD Effluent Concentration (mg/l)			
	160	140	40	20
1.1	$26,447	$26,695	$29,142	$30,591
1.2	28,329	28,595	31,215	32,767
1.3	30,178	30,461	33,253	34,906
1.4	31,997	32,298	35,258	37,011
1.5	33,790	34,107	37,233	39,084
1.6	35,557	35,891	39,181	41,129
1.7	37,302	37,652	41,103	43,146
1.8	39,024	39,391	43,001	45,139
1.9	40,727	41,110	44,878	47,109
2.0	42,412	42,810	46,734	49,057

In certain cases you may decide to expand and/or upgrade the existing treatment facilities. This decision involves additional capital costs. The annual fixed capital costs for a number of upgraded plants are shown in Table A-4. These costs will vary with the wastewater design flow and with the BOD design removal rate. Once the waste treatment facility capacity is defined in terms of the wastewater design flow and the BOD capacity design removal rate, the capital costs become fixed costs until further decisions are made to again augment the treatment plant. The operation of the plant in this case will involve variable costs which will increase nonlinearly with changes in the actual BOD effluent concentration level and the actual wastewater flow rate. The additions to the plant will not become available for actual use until two periods after the decision to upgrade and/or add to the plant has been made.

TABLE A-3

MUNICIPAL USER CHARGES

Wastewater (MGD)	BOD Effluent Concentration (mg/1)			
	200	140	120	100
1.0	$36,610	$36,610	$36,610	$36,610
1.1	40,271	40,271	40,271	40,271
1.2	43,932	43,932	43,932	43,932
1.3	47,593	47,593	47,593	47,593
1.4	51,255	51,255	51,255	51,255
1.5	54,915	54,915	54,915	54,915
1.6	58,577	58,577	58,577	58,577
1.7	62,238	62,238	62,238	62,238
1.8	65,899	65,899	65,899	65,899
1.9	69,560	69,560	69,560	69,560
2.0	73,221	73,221	73,221	73,221

TABLE A-4

CAPITAL COSTS ($)

Design Wastewater (MGD)	Design BOD Effluent Concentration (mg/l)	
	20	10
1.5	$61,968	$69,235
1.7	69,269	77,394
1.8	72,884	81,433
2.0	80,050	89,438
2.1	83,603	93,408
2.2	87,137	97,387
2.3	90,653	101,280

ALTERNATIVE CONTROL POLICIES FOR WATER QUALITY MANAGEMENT: A SIMULATION GAMING APPROACH

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